DEVOLOPMENT OF SOFTWARE TO EVALUATE ROOF FALL RISK IN BORD AND PILLAR METHOD - DEPILLARING PHASE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

BY

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National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the thesis entitled "**DEVOLOPMENT OF SOFTWARE TO EVALUATE ROOF FALL RISK IN BORD AND PILLAR METHOD - DEPILLARING PHASE"** submitted by **Sri Manuka Shiva Sai** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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CONTENTS

ABSTRACT

Roof fall is one of the biggest problems of the bord and pillar coal mines during depillaring phase. Roof fall not only causes great damage to the mining equipment but also to the miners. It is clear that development of software is essential for calculation of roof fall risk in bord and pillar coal mines depillaring phase in order to reduce the accidents. Software has been developed and tested on two coal mines - seam 2, main panel of RK-5 and seam 2, main panel of RK-6 underground coal mine, SCCL India. Corresponding roof fall risk was calculated and the best combination of the parameters causing roof fall risk was evaluated to reduce the risk.

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Chapter-1

INTRODUCTION

INTRODUCTION

1.1 GRNERAL

Roof fall in underground coal mines are one of the most significant hazards for miners. Roof fall can threaten miners, damage equipment, disrupt ventilation and block critical emergency escape routes. The hazardous nature of roof fall risk can be illustrated from statistics of mine accidents of Indian mines.

Table 1: Trend of Fatal Accidents in Coal Mines due to roof falls in India [(2)]

Sl. No.	Year	No. of roof falls
1	1998	35
2	1999	33
3	2000	27
4	2001	30
5	2002	23
6	2003	18
7	2004	26
8	2005	18
9	2006	13
10	2007	13
11	2008	14
12	2009	17
13	2010	11

A total no. of 278 fatal accidents took place due to roof fall. Accidents due to fall of roof occurred in same proportion in bord and pillar development as well as depillaring methods. In underground coal mines, bord and pillar is one of the oldest method used for extraction of flat and tabular coal seams. Pillars are left behind to support roof and preventing it from collapse. To increase the utilization of coal the pillars are extracted after development known as depillaring method. Depillaring mining is one of the most hazardous activities because it creates an inherently unstable situation. The process of depillaring method removes the main support after extraction of the pillars to a extreme extent and allows the roof and overlying rocks to cave. As a result pillar line is extremely dynamic and highly stressed environment. Software was developed based on the equation designed to calculate the risk of roof fall during retreat mining in room and pillar coal mines [(1)].

1.2 OBJECTIVES

1. Study of different parameters responsible for roof failure in underground coal mines using bord and pillar method, depillaring phase.
2. Development of software for calculation of risk factor of roof fall in underground mines using bord and pillar method, depillaring phase.

1.3 METHODOLOGY

In order to achieve the above said objectives, the following methodology was adopted.

- **Literature Review:**

  All the past research work carried out by researchers, academicians, scientists etc. related to present topic was reviewed to gain some knowledge.
- **Study of parameters:**

  All the parameters which are responsible for roof failure are clearly studied.
- **Development of software:**

  Software was developed in ASP.NET for the calculation of the risk factor. The coding language used was c#.
- **Collection of data:**

  Data was collected from 2 different mines and risk factor was calculated using developed software.

Chapter-2

LITERATURE REVIEW

LITERATURE REVIEW

2.1 PARAMETERS CONTRIBUTING TO THE ROOF FALL DURING DEPILLARING METHOD

The parameters contributing to roof fall during depillaring method can be divided into 3 categories and they are

- Geological parameters
- Design parameters
- Operational parameters

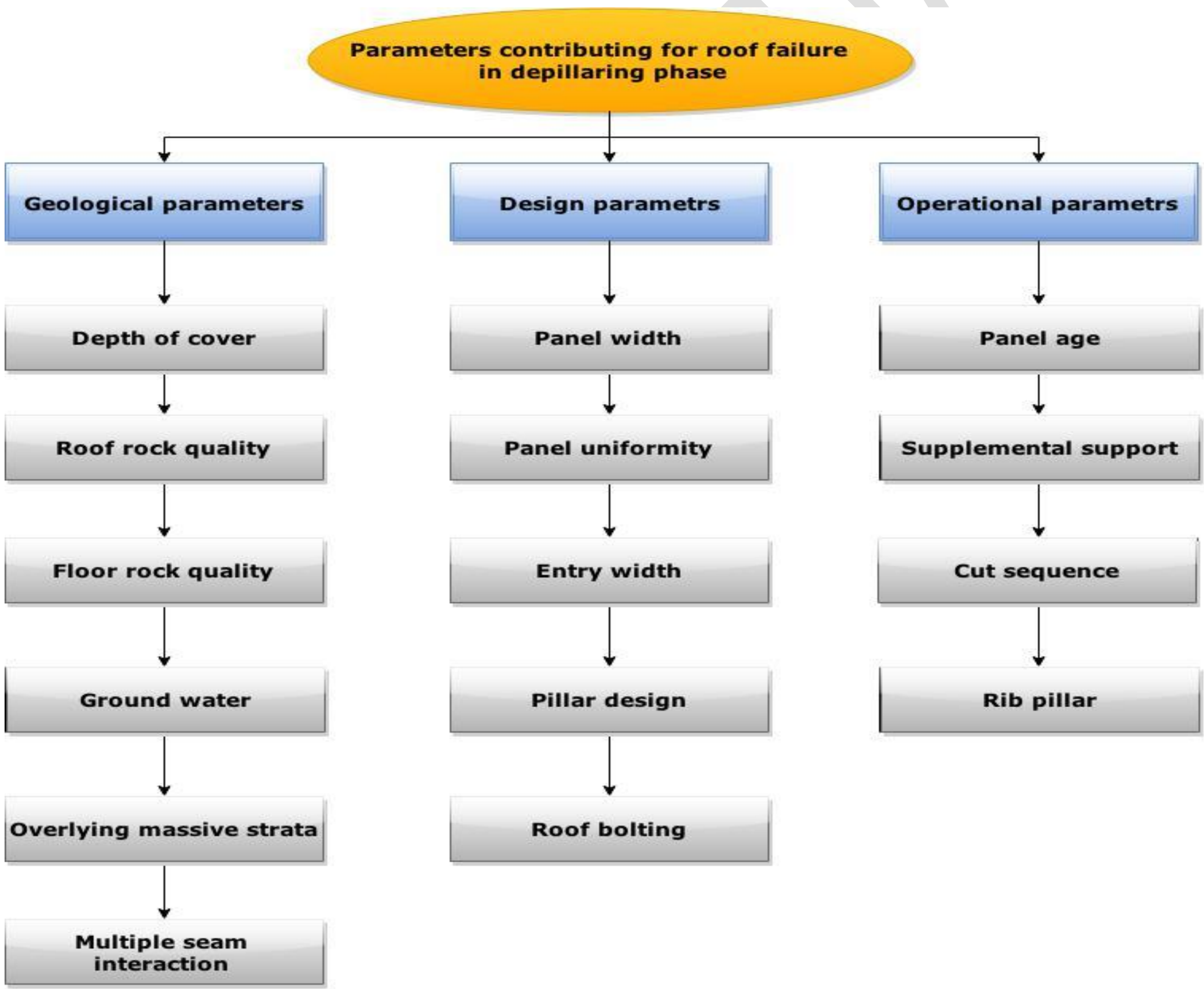

Figure 1: Flow chart of major parameters contributing for roof failure in depillaring phase

2.1.1 GEOLOGICAL PARAMETERS

2.1.1.1 Depth of cover [3]

Increasing the depth leads to increase of virgin stress levels in rock mass both vertically and horizontally. So achieving sufficient stability is harder at higher depths and special precautions are required to ensure ground stability.

2.1.1.2. Roof Rock Quality [5]

Quality of roof fall rock has an important role in occurrence of roof fall. Various methods have been presented for classification and evaluation of roof in coal mines, but most applicable is RMR (roof mass rating) When RMR approaches ‘0’ roof is weak and when it approaches ‘100’ roof is stronger. Based on RMR risk can be divided in to 5 categories.

a) Extreme 0-45

b) High 45-55

c) Moderate 55-65

d) Low 65-85

e) Negligible 85-100

2.1.1.3 Floor Rock Quality [4]

Floor, pillar and roof treat a system in bord and pillar mines. It plays important role. When floor doesn’t have suitable quality pillar penetrate in to the floor, which leads to roof convergence and ultimately a failure. If floor heave is found to a great extent then it considered as weak floor. If no heave is observed then it is strong. Rest of the cases it is considered as moderate.

2.1.1.4. Ground water [1]

Presence of groundwater resource and strata containing water above extracting panel is one of effective parameters of roof instability. If roof is dry, roof fall is not probable, if roof is wet, the probability of roof fall is low, if dripping occurs, the probability is high, and if flow of water is steady then probability is extreme.

2.1.1.5. Overlying massive strata [1]

One of the most important influencing parameters on roof cavability is the existence of massive strata such as sill over the panel. Massive strata can cause intense roof fall during retreat mining because these strata tend to be hang up in large spans, but after achieving a critical span, they break violently. Based on researches done by Anderson, the nature of immediate roof strata (up to 20 m over the coal seam) has an important role in cavability and creation of gob. Therefore, if the massive strata are in this range, the probability of roof fall is high. In these situations, partial pillar extraction with proper cut sequence is effective in order to prevent violent roof fall.

2.1.1.6. Multiple-seam interaction (1)

In many of coalfields, coal seams are formed close to each other and as series separated by rock strata (interburden). The mining of two adjacent seams is called multiple-seam mining and the ground control problems caused by this mining method are called multiple-seam interaction. Ground instability is greatest hazard due to multiple seam interaction. If thickness of extracting coal seam is ‘H’ and interburden thickness is ‘T’ then

$T < 4H$ interaction is extreme

$4H < T < 10H$ interaction is high

$10H < T < 24H$ interaction is moderate

$24H < T < 60H$ interaction is low

$T > 60H$ interaction is negligible.

2.1.2. DESIGN PARAMETERS

2.1.2.1. Panel width (1)

Panel width affects abutment loads distribution and over- burden caving mechanism during retreat mining. Moreover, with increase of panel width, the height of tensile zone developed in the overburden increases, which can cause violent failure and eventually full caving of overburden. Width to depth ratio panels is divided into three categories:

- sub critical ($P/H < 2\tan b$),
- Critical ($P/H = 2\tan b$),
- Super-critical ($P/H > 2\tan b$),

Where P is the panel width, H is the panel depth and b is the abutment angle. Super-critical panels have more width in comparison with two other categories.

2.1.2.2. Panel uniformity (4)

Panel shape and panel’s pillars shape and size are important in panel uniformity. Because irregular panel shapes make pillar lines uneven during retreat mining and this causes unpredictable an uncontrollable roof falls. Moreover, panel development consisting uniformly sized pillars is recommended strongly, because non-uniform and unequal sized pillars cause non-uniform stress distribution and therefore decrease the roof stability.

2.1.2.3. Entrywidth (1)

One of the most important method of decreasing the roof instability at intersections is that entries creating an intersection should be mined to the minimum possible width, in order to make the operation of extraction safe and the haulage equipment possible. Regarding the equipment which is used in room and pillar mines now a-days (continuous miner, shuttle car and LHD), the proper width of entries is about 4.5 to 5 m and also based on researches done by Jeffrey at width more than 7 m, roof fall and support problems are probable.

2.1.2.4. Pillar design (4)

Proper pillar design has a significant role in roof stability. Analysis of retreat mining pillar stability (ARMPS) program is an effective means for pillar design and prediction of pillar stability during retreat mining. ARMPS was developed by Mark and Chase in 1997. Stability factor depends on depth of cover and roof quality (CMRR). If H is the depth and S is the safety factor of pillar then design is said to be suitable if it follows Table 2 else it is considered as unsuitable.

Table 2: Suitable safety factor for stability of the pillars during retreat mining (4)

Depth of cover (H)	Weak and intermediate roof (RMR < 65)	Strong roof (RMR > 65)
H < 200 m	≥ 1.5	≥ 1.4
200 < H < 400 m	0.9 ≤ S < 1.5	0.8 ≤ S < 1.4
H > 400 m	S > 1.5	1.4

2.1.2.5. Roof bolting (1)

Experimentally, installation of one roof bolt in one square meters of roof (bolt density = 1) in coal mine entries seems to be safe but it is not adequate at intersection because intersections are subjected to abutment loads during retreat mining, and therefore require extra roof bolting. Based on bolt density, the probability of roof fall risk at intersections is divides into three categories:

a) High, when bolt density is less than 1;

b) Moderate, when bolt density is between 1 and 1.5;

c) Low, when bolt density is more than 1.5.

2.1.3. OPERATIONAL PARAMETERS

2.1.3.1. Panel age [1]

As time passes, the roof of mine becomes weaker .Supplemental bolting is often required, particularly in intersections, to prepare old panels for retreat mining. If the panel age is less than one year, no additional support is needed and the probability of roof fall is low. But in older panels, the probability of roof fall increases.

2.1.3.2. Supplemental support [1]

Supplemental roof support is necessary in depillaring phase to increase the safety and minimize the risk of injury from roof falls. Timber posts and mobile roof supports (MRSs) provide supplemental support for retreat mining. Nowadays, using MRS is recommended strongly because using timber posts as pillar line supports has many disadvantages and the most important is that timber posts are passive supports and roof convergence would be small.

2.1.3.3. Cut sequence [1]

Mines employ a wide variety of cut sequences to recover pillars and most of them can be divided into three categories

- Left– right (also called Christmas tree or twinning) in which cuts are taken on both sides of the entry and it does not require place changes and bolting,
- Outside lift in which cuts are taken on just one side and similar to left–right, it does not place changes and bolting,
- Cut sequences that require cuts to be bolted.

These methods are usually used when the pillars are so large that they must be split before they are fully recovered. Split-and-fender and pocket-and-wing are two common types of these methods.

Chapter-3

CALCULATION OF ROOF FALL RISK

CALCULATION OF ROOF FALL RISK

Risk is defined as the chance of occurrence of unwanted events that will have adverse effects on purposes. It is measured in terms of probability (P) and consequence (C). Roof falls during retreat mining continue to be one of the greatest geotechnical risks faced by underground coal miners and cause a lot of loss, injury or fatalities. Therefore, the roof fall risk can be defined as

$$R_{rf} = P * C$$

3.1. PROBABILITY [(6)]

In order to make the roof fall probability quantitative, two measures have been considered. The first one is to assign the probability factor (PF) for each sub-category. The second one is to give a weight to each parameter. The probability factor is an index which represents the probability of roof fall for each sub-category and was obtained from Table 6 based on proposed method by Joy[(6)]. Based on Table 6, the probability factor can be a number between 0 and 4; 0 shows that the roof fall probability is negligible and 4 shows that the roof fall probability is extreme. Since the effects of different parameters on roof fall are not the same, it is necessary to give a weight to each parameters based on its importance on roof fall occurrence. In this study, a weight between 1 and 10 was assigned to each parameter based on judgments of mining engineers and ground control experts (Tables 3–5). 1 indicates the least effective parameter and 10 shows the most effective parameter of roof fall.

The probability of roof fall during retreat mining is calculated as

$$\mathbf{P} = \left[\left(\sum_{i=1}^{n} PF_i * W_i\right) / \left(\sum_{i=1}^{n} MPF_i * W_i\right)\right] * 100$$

Where, PF_i, MPF_i and Wi are probability factor, maximum probability factor and weight of i-th parameter, respectively. The MPF for nine parameters is 3 and for the other parameters is 4 (Tables 3–5). Therefore, the above equation can be summarized as follows:

$$P = 0.33 * \left[\left(\sum_{i=1}^{n} PF_i * W_i\right)\right]$$

Table 3: Geological parameters influencing roof fall risk [1]

Sl. No.	Parameters	Probability factor	Weight
1	Depth of cover (m) • Less than 40 • Between 40 and 200 • Between 200 and 400 • Between 400 and 600 • More than 600	4 1 2 3 4	9
2	Roof rock quality (CMRR) • Less than 45 • Between 45 and 55 • Between 55 and 65 • Between 65 and 85 • More than 85	4 3 2 1 0	10
3	Floor rock quality • Weak • Intermediate • Strong	3 2 1	4
4	Groundwater • Dry roof • Wet roof • Dripping • Steady flow	0 1 3 4	2
5	Overlying massive strata • Do Not present • Present Less than 20 m • Present More than 20 m	0 3 1	5
6	Multiple-seam interaction/ Interburden thickness • Not present • present/Less than 10h • Present/Between 10h and 24h • Present/Between 24h and 60h • Present/More than 60h	0 4 3 2 1	7

Table 4: Design parameters influencing roof fall risk [1]

Sl. No.	Parameters	Probability factor	Weight
1	Panel width • Sub-critical • Critical • Super-critical	 1 2 3	3
2	Panel uniformity • Uniform • Partly uniform • Non-uniform	 1 2 3	1
3	Entry width (m) • Less than 5 • Between 5 and 7 • More than 7	 1 2 3	8
4	Pillar design • Suitable • Unsuitable	 1 4	6
5	Roof bolting • Bolt density less than 1 • Bolt density between 1 and 1.5 • Bolt density more than 1.5	 3 2 1	7

Table 5: Operational parameters influencing roof fall risk [1]

Sl. No.	Parameters	Probability factor	Weight
1	Panel age (year) • Less than 1 • Between 1 and 2 • More than 2	 1 2 3	2
2	Supplemental support • Mobile roof support • Timber post	 1 4	7
3	Cut sequence • Outside lift • Left–right • Other sequence	 1 2 3	6
4	Final stump • Proper • Improper	 1 4	8

Table 6: Probability of an event in mining industry [1]

Sl. No.	Probability	Description	Probability Factor (PF)
1	Extreme	Common or frequent occurrence, ‘‘happens all the time’’ ’	4
2	High	Is known to occur, ‘‘it has happened or it probably will happen’’	3
3	Moderate	Could occur, ‘‘I have heard of it happening’’	2
4	Low	Not likely to occur, ‘‘highly unlikely to happen’	1
5	Negligible	Practically impossible, ‘‘doubt it could ever happen’	0

3.2. CONSEQUENCE [6]

The roof fall during retreat mining can cause injury, disability and fatality of miners, damage to equipment, disruption and delay in mining operation simultaneously. Furthermore, most of roof falls caused burial of continuous miner and MRS. The necessity to recover these equipment’s because of their high initial costs, has caused several days of delay in mine production. Therefore, consequence of roof fall during retreat mining is catastrophic, which is the highest rank of consequence, and the number 1 (highest rank) can be allocated to it, which cause elimination of consequence term from derived equation

3.3. EVALUATION OF ROOF FALL RISK [1]

Considering what was mentioned in two previous sections, derived equation can be presented as:

$$R_{rf} = 0.33 * \left[\left(\sum_{i=1}^{n} PF_i * W_i\right)\right]$$

Based on this equation, the roof fall risk during retreat mining (Rrf) is an amount between 0 and 100. When the Rrf is approaching to 0 the roof fall risk during retreat mining is low and when Rrf is approaching to 100 the roof fall risk is very high. In this study, the roof fall risk during retreat mining based on Rrf values is divided into four categories: low, medium, high, and very high (Table 7).

Table 7: Classification of roof fall risk during retreat mining [1]

Risk category	Rrf value	Roof fall probability	Level of roof fall risk
Low	0-28	Improbable	Acceptable
Moderate	28-48	Possible	Acceptable with management review, monitoring and auditing
High	48-70	Probable	Undesirable and requires control measures widely
Very high	70-100	Very probable	Unacceptable

Chapter-4

DEVELOPMENT OF SOFTWARE

DEVELOPMENT OF SOFTWARE

4.1. SOFTWARE REVIEWS

The Microsoft Visual Studio 2010 is used for the development of the software, in which the frontend is designed using ASP.NET and coding was written in C# language.

4.2. MICROSOFT VISUAL STUDIO

Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. It is used to develop computer programs for Microsoft Windows, as well as web sites, web applications and web services. Visual Studio uses Microsoft software development platforms such as Windows API, Windows Forms, Windows Presentation Foundation, Store and Microsoft Silverlight. It can produce both native code and managed code

4.3. ASP.NET [7]

Asp.net is an open source server side web application framework designed for web development to produce dynamic web pages. It was developed by Microsoft to allow programmers to build dynamic websites, web applications and web services. Asp.net Web pages, known officially as Web Forms, are the main building blocks for application development. Web forms are contained in files with a ".aspx" extension; these files typically contain static (X) HTML markup, as well as markup defining server-side Web Controls and User Controls where the developers place all the rc content for the web page.

4.4. C SHARP (PROGRAMMING LANGUAGE) [8]

C# (pronounced as see sharp) is a multi-paradigm programming language encompassing strong typing, imperative,declarative, functional, generic, object-oriented (class-based), and component-oriented programming disciplines. It was developed by Microsoft within its .NET initiative and later approved as a standard by Ecma (ECMA-334) and ISO (ISO/IEC 23270:2006). C# is one of the programming languages designed for the Common Language Infrastructure.

4.5. PROGRAM STRUCTURE

- Front end of the application is designed and developed in asp.net. Several tools such as text box, label, button and drop down list are used in the design.

- The background language was written in c sharp language where all the parameters are coded as per the theory explained earlier.
- The event button is created in the software where we get the result when all the required data is entered and pressing the button..

4.6. SOFTWARE APPROACH

- The program consists of a single screen where all data should be entered and the result appears in the same page too when the button "calculate" is clicked.
- First of all the folder roof fall risk is opened and run risk.exe.
- The program consists of seven text boxes which are to be entered by an integer value and nine drop down list which are to be selected.
- After entering all the data, click on "calculate" button to know the roof fall risk.
- Table 7 represents the level of roof fall risk based on the software results.
- Figure 2 and 3 represents the flowchart and layout of the program.

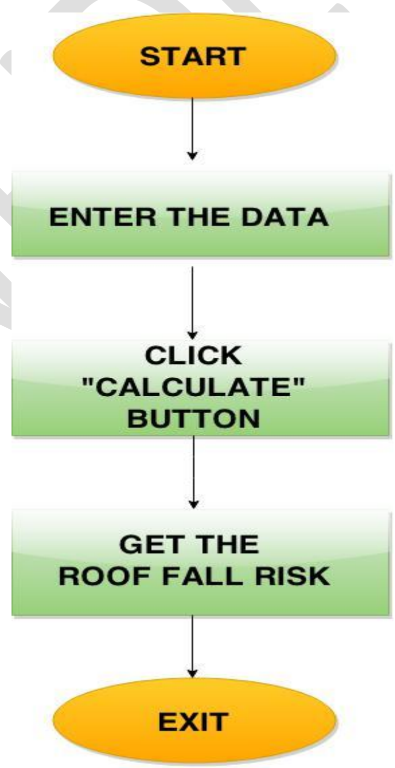

Figure 2: Flow chart of the program

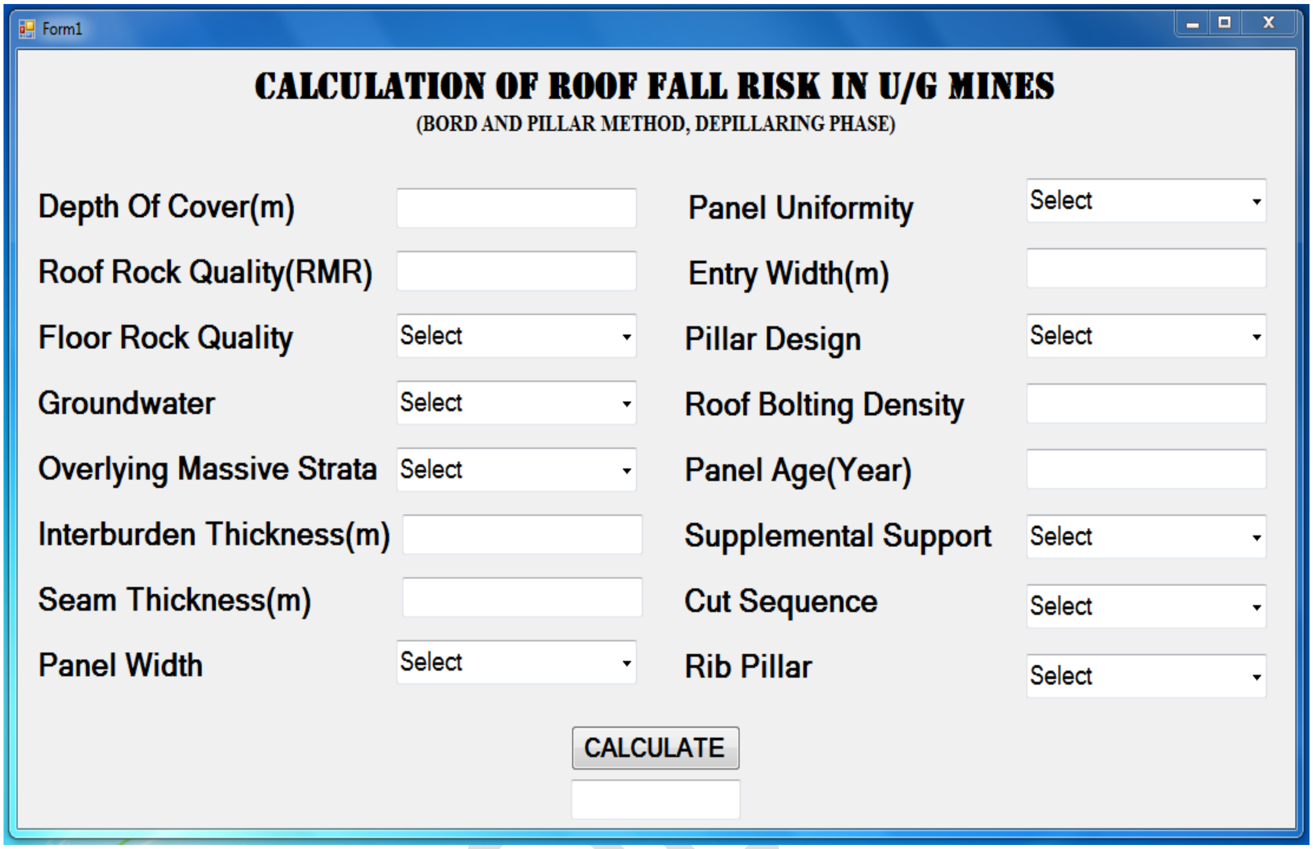

Figure 3: Layout of the program

Chapter-5

APPLICATION OF METHODOLOGY

APPLICATION OF METHODOLOGY

5.1. CASE STUDY

The developed software was applied on two different underground coal mines namely seam-2, main panel of RK-5 and seam-2, main panel of RK6 of Singareni Collieries Company Limited (SCCL) located in Godavarikhani district, Telangana state, India. The summary of parameters of RK-5 and RK-6 has been presented in Table 8 and 9.

Table 8: Data collected from RK-5 mine

Sl. No.	Parameters	Data
1.	Depth of cover (m)	180
2.	Roof rock quality	56
3.	Floor rock quality	Intermediate
4.	Ground water	Wet roof
5.	Overlying massive strata	Present < 20m
6.	Multiple seam interaction	Present/ less than 10H
7.	Panel width	Sub critical
8.	Panel uniformity	Uniform
9.	Entry width (m)	4.5
10.	Pillar design	Suitable
11.	Roof bolting density	1.75
12.	Panel age (Years)	1.5
13.	Supplemental support	Timber post
14.	Cut sequence	Left right
15.	Final stump	proper

Table 9: Data collected from RK-6 mine

Sl. No.	Parameters	Data
1.	Depth of cover (m)	170
2.	Roof rock quality	56
3.	Floor rock quality	Intermediate
4.	Ground water	Dry roof
5.	Overlying massive strata	Present < 20m
6.	Multiple seam interaction	Present/ less than 10H
7.	Panel width	Sub critical
8.	Panel uniformity	Uniform
9.	Entry width (m)	4.2
10.	Pillar design	Suitable

11.	Roof bolting density	1.75
12.	Panel age (Years)	1.5
13.	Supplemental support	Timber post
14.	Cut sequence	Left right
15.	Final stump	proper

5.2. RESULT

All the above data are entered into the software and found that roof fall risk was around 52.47 in RK-5 mine and 51.81 in Rk-6 mine which represents high risk category as the roof fall risks are between 48 and 70. By changing the supplemental support from timber post to mobile roof support, the roof fall risk for RK-5 mine was reduced to 45.54 and for RK-6 mine it was reduced to 44.88 which interprets moderate category i.e. between 28 and 48. Since this software provides the roof fall risk in advance so that preventive measures should be taken to avoid the accidents. The pictorial view of calculation of roof fall risk of both the coal mines have been represented in Figures 4 - 7.

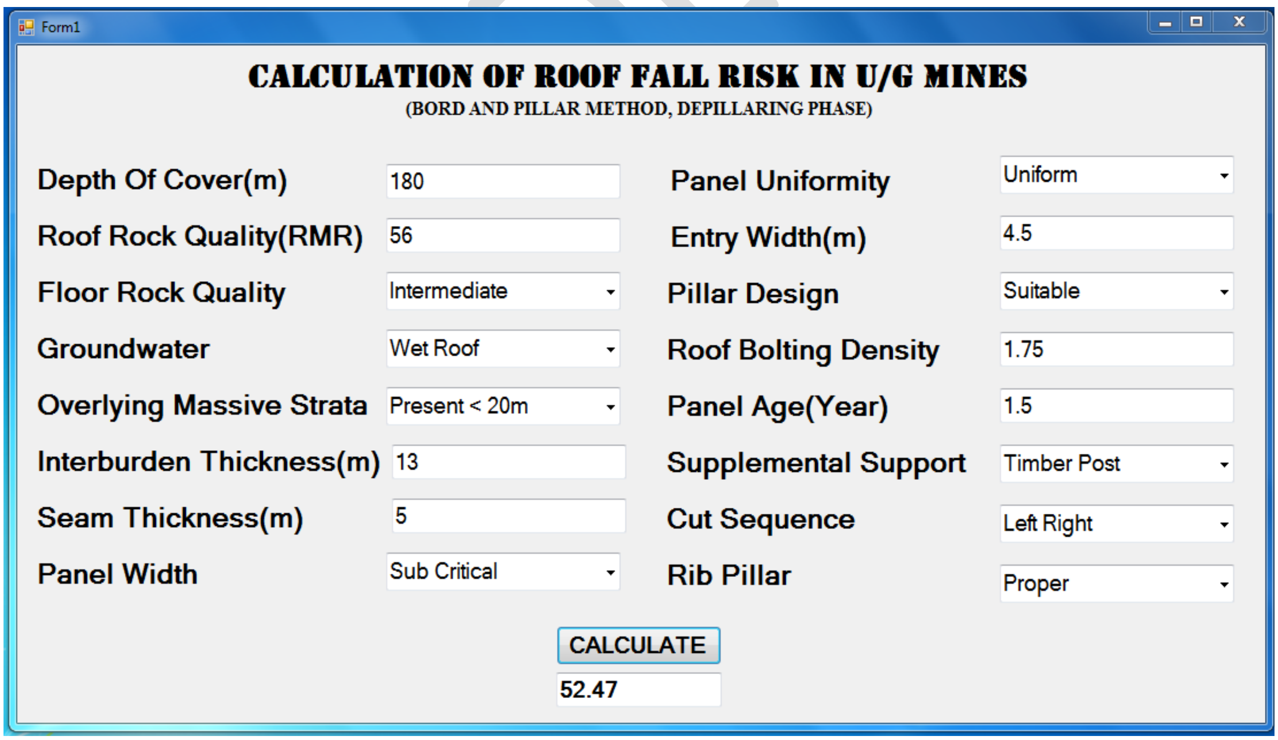

Figure 4: Pictorial view of software of RK-5 mine when supplemental support is timber post

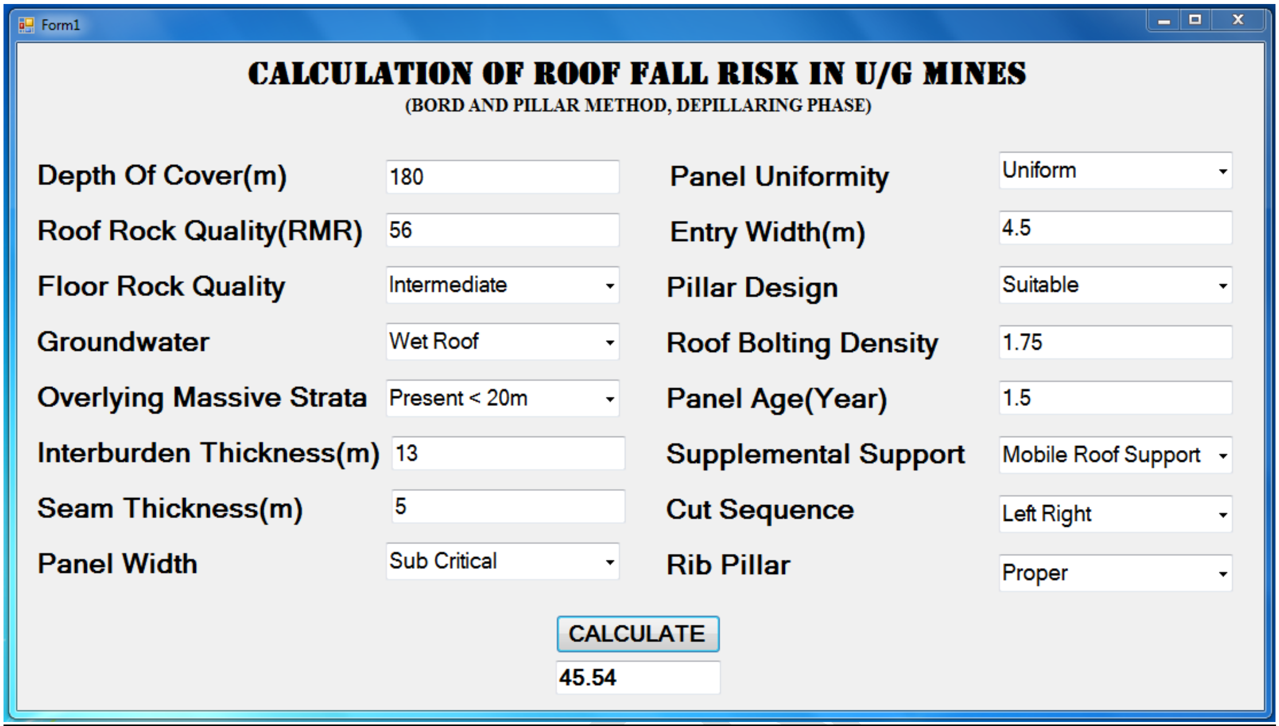

Figure 5: Pictorial view of software of RK-5 mine when supplemental support is mobile roof support

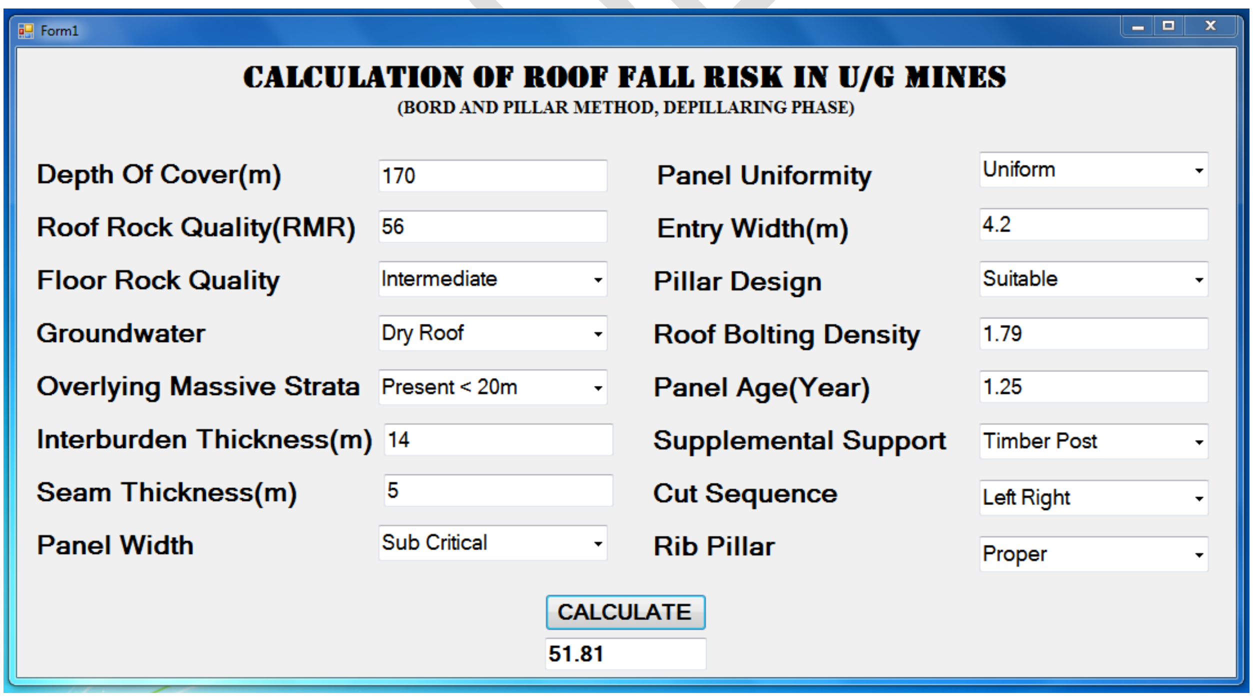

Figure 6: Pictorial view of software of RK-6 mine when supplemental support is timber post

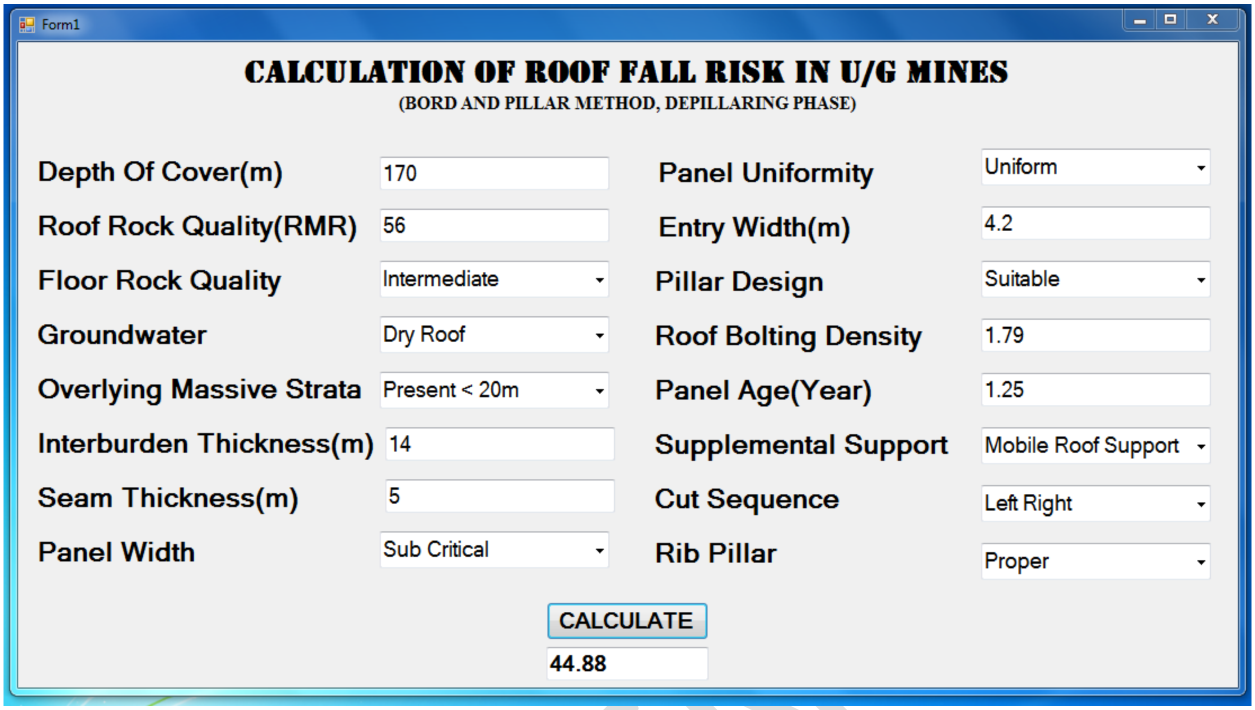

Figure 7: Pictorial view of software of RK-6 mine when supplemental support is mobile roof support

Chapter-6

CONCLUSIONS

CONCLUSIONS

Depillaring method is mostly associated with high amount of risk and most of the accidents causes due to roof failure. By development of software for the prediction of roof failure we can reduce the number of accidents to a certain extent. Use of software eases the calculation of roof fall risk with different combinations of parameters causing roof failure and finds the suitable risk factor. The combination with the least risk factor can be adopted in the mine and hence accidents due to roof failure can be reduced.

When changing the support from timber to mobile roof support, the roof fall risk of RK-5 and RK-6 underground coal mines was changing from high risk category to moderate risk category so we can take preventive measures in advance with the proposed software to reduce the roof fall risk to a certain extent with feasible constraint.

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